Dis Cat SPODUMENE

JULIEN

ON

SPODUMENE and its ALTERATIONS,

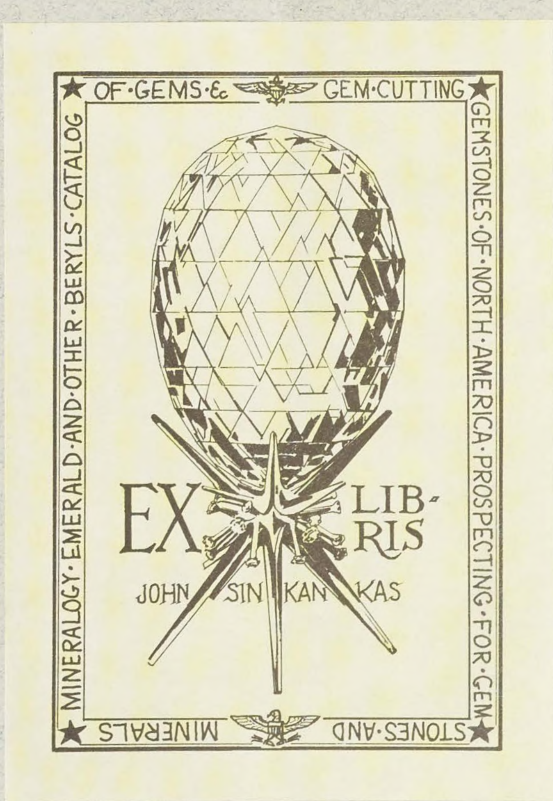
FROM THE

Granite Veins of Hampshire Co., Mass.;

BY

ALEXIS A. JULIEN.

[From the ANNALS OF THE N. Y. ACADEMY OF SCIENCES, VOL. I, No. X.]
1879.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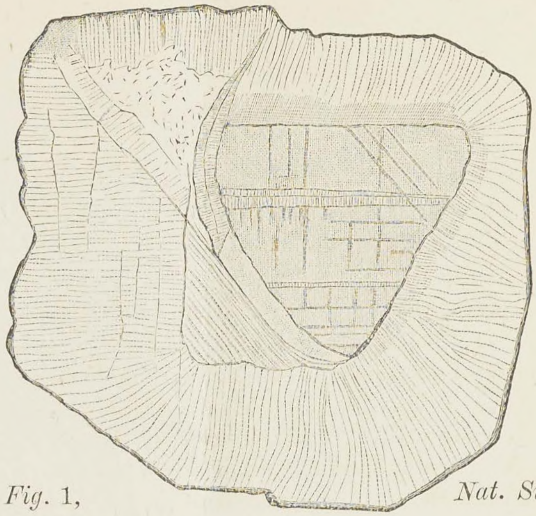

Fig. 1, *Nat. Size.*

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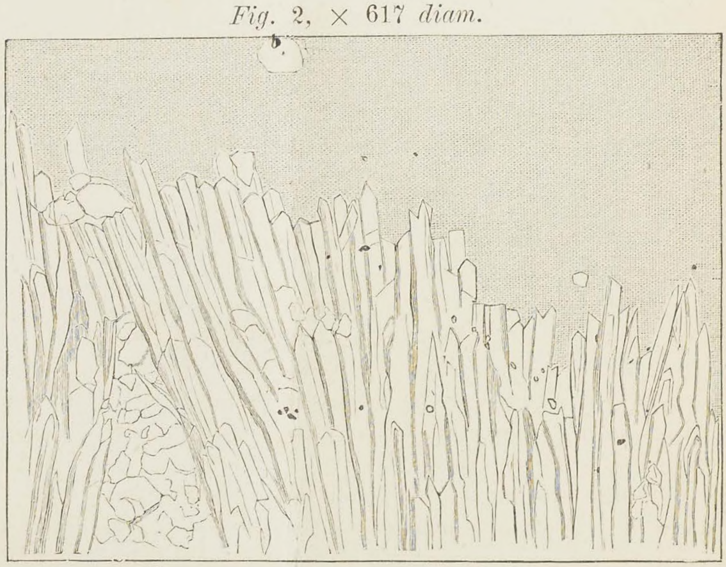


Hundredths.

One Tenth of a Millimeter.

[FROM THE ANNALS OF THE N. Y. ACADEMY OF SCIENCES, VOL. I, NO. 10, NOVEMBER, 1879.]

XXVIII.—*On Spodumene and its Alterations, from the granite-veins of Hampshire County, Mass.*

BY ALEXIS A. JULIEN.

Read June 10th and November 18th, 1878.

The mineral Spodumene is one of rather scanty occurrence, in regard both to abundance and to the number of its known localities. In Europe, it has been reported from only a half-dozen places in Scotland, Ireland, Sweden and the Tyrol; in this country, in only four localities outside of Massachusetts; but, in the eastern part of that State, it occurs at Sterling, and in crystals of remarkable size and perfection, at six localities, within Hampshire County in the western part. Here, as usual, it was found in coarse granite veins—huge lenticular masses of that rock, with sometimes great extension but little thickness—succeeding each other at intervals of several miles, along the strike and enclosed between the highly-tilted beds of the stratum of Staurolitic mica-schist. This is one of the lowest members of the group of crystalline schists of that region, consisting in descending order of the following series:

1—Chloritic, Hornblende, and Talc Schists, enclosing layer-veins of Magnetite, Rhodonite, Rutile, Zoisite, Emery (at Chester), Margarite, Diaspore, etc.

2—Micaceous grits, often slaty, fine-grained, siliceous, and arenaceous, with quartz-veins, mostly barren of minerals.

3—Ottrelitic Clay-slate, the well-known Phyllite of western Massachusetts: frequently intersected by heavy veins of milky-white quartz, of which the smaller sometimes carry blue Kyanite, Graphite, Cummingtonite, etc.

4—Staurolitic Mica-schist, rich in Garnets and more rarely Kyanite: everywhere marked by the intercalated layer-veins of coarse Orthoclase-granite, with Beryl. Several of these embrace secondary veins of albitic granite, containing a large variety of interesting minerals afterwards enumerated.

5—Granitoid gneiss, generally in heavy-bedded, coarse masses, rich in Orthoclase.

Localities of Occurrence.—The localities at which Spodumene has been found are as follows: All these veins, except II, were originally opened by E. Emmons, C. U. Shepard, and E. Hitchcock, many years ago.

I—In the northern part of the town of Goshen, on the Manning farm, over two miles north of the village of Goshen Center, on the road to Ashfield.

II—In the town of Goshen, on the farm of Levi Barrus, about one mile west of the preceding locality.

III—In the northwest corner of the town of Chesterfield, and two miles southeast of the village of East Cummington, at a granite ledge on the farm of A. Macomber. This small vein I first opened in the year 1870.

IV—At the village of Chesterfield Hollow, about two miles south of the last locality, in a ledge above the village, called "Isinglass Rock."

V—Four miles further south, in the town of Huntington (formerly Norwich), on Walnut Hill, in the vein celebrated for its remarkable crystals of Spodumene.

VI—In the town of Chester, about one mile north of Chester Village.

In the first locality mentioned, in the town of Goshen, the vein is not visible in place, but many large angular fragments and boulders, on the south-eastern slope of a low hill, indicate its close vicinity. The Spodumene here occurs in irregular and imperfect bladed crystals, sometimes two inches in diameter, and is much stained by films of Pyrolusite derived from the decomposition of the Garnet. With a little search. individuals were readily found in a partially altered condition, which had assumed a micaceous and radiated structure, and consisted of a soft and yellowish form of impure Cymatolite.

In the second of the Goshen localities referred to, on the Barrus farm, a heavy and coarse granite vein, accompanied in places with a contiguous vein of reddish-white quartz of corresponding size, forms the western wall of a low and somewhat marshy valley, thickly strewn with large and but little rounded granite boulders. In the visible portion of the vein, the only mineral of interest is Beryl, occurring in small and scattered green crystals. But, in the boulders, Spodumene has been of

Beryl

frequent occurrence, mostly in rectangular prismatic masses, up to 18 inches in length, but occasionally in fair crystals, with good terminations, two or three inches long. The predominence of the planes i-i and i-ì, commonly results in the development of long square prisms. Its association is very interesting, and will be hereafter described. It was here that the same pseudomorphous mineral after Spodumene was originally discovered by C. U. Shepard, and announced in 1867, under the name of Cymatolite, by publication in Dana's "System of Mineralogy." His description and partial analysis, and a complete analysis by Burton, are embraced in that work under the species Pihlite, and the definite establishment of Shepard's species has apparently awaited the fuller investigation dependent upon a rediscovery of a purer material in sufficient supply.

At Chesterfield Hollow, in the mass of coarse Orthoclase-granite which forms the southern abutment of the hill above the village, I found a small and long-abandoned opening, and re-opened and excavated it during portions of three successive summers. The Spodumene was here found almost altogether in the form of well-defined crystals, often thickly grouped and traversing the smoky Quartz in every direction, and showing all the stages of alteration into Cymatolite, from a mere enveloping film, as an outer crust, and also dulling internally the lustre of its prominent cleavage-surfaces, to a pseudomorphous alteration of the entire crystal. Many of its crystals must have been of unprecedented and enormous size, as they were found, mostly in the altered condition, up to a length of 35 inches, actually measured while lying in the vein, and with a diameter which sometimes reached 10 or 11 inches. However they were, together with their quartz-gangue, so traversed by innumerable minute fissures, occupied but only feebly cemented by the films of Pyrolusite, that no perfect specimens could be extracted at all approaching these dimensions. On the other hand, acicular crystals were observed in abundance, penetrating the Quartz in an irregular and confused net-work; good single terminations were not uncommon; and even one or two short and doubly-terminated crystals were found in a partially pseudomorphous condition. Besides this form of alteration, several other pseudomorphs after Spodumene in various materials, Killinite, Quartz, Albite,

and Muscovite, were discovered, of which the description, and the nature of the process of alteration, will be discussed beyond.

The vein in Huntington has furnished the finest crystals of Spodumene for all mineralogical cabinets, sometimes 16 inches in length, as well as the material from that locality for the well-known and excellent analyses of Smith and Brush, and quite recently of Doelter.

The vein in the township of Chester was first discovered and opened by E. Emmons, and the Spodumene was found to be associated with Smoky Quartz, Muscovite, Cleavelandite, Indicolite, etc. In 1870, however, I could find no Spodumene remaining in a small vein of this general character, showing traces of blasting, which seemed to be the one opened by Emmons.

Analyses of Spodumene.—In the following table, I have now to present two analyses made on specimens of Spodumene from this region, probably almost unaltered.

In all analyses given in this paper, the material had been previously picked out under the loup, finely ground, and dried at 100° C.

I—Unaltered Spodumene from the Levi Barrus locality in Goshen. The material, carefully selected, was of a bright grayish-green color, high lustre, and translucent to sub-transparent.

II—Unaltered Spodumene from Chesterfield Hollow. The material was taken from the core of an enormous crystal, whose exterior was altered into a white crust of Cymatolite. It was of the same bright color and lustre as that of the preceding locality, and possessed remarkable translucency, dimmed in a hand-specimen by the numerous fissures, but with its constituent grains perfectly transparent.

III—Mean of analyses I and II. Also, for comparison, the following two analyses of the same mineral from the other Massachusetts localities (Am. J. Sci., II, xvi, 372, 1853).

IV—Spodumene from Norwich (now called Huntington). Analysis by Smith and Brush.

V—Spodumene from Sterling (in eastern Massachusetts). Analysis by Smith and Brush.

ANALYSES OF SPODUMENE.

	I	II	III	IV	V
	Goshen (Julien.)	Chesterf'ld (Julien.)	Mean of I & II.	Norwich (Smith & Brush.)	Sterling (Smith & (Brush.)
Silica,	63.27	61.86	62.57	64.04	64.50
Alumina,	23.73	23.43	23.58	27.84	25.30
Ferric Oxide,	1.17	2.73	1.95	.64	2.55
Manganous Oxide,	.64	1.04	.84	——	——
Magnesia,	2.02	1.55	1.78	trace.	.06
Lime,	.11	.79	.45	.34	.43
Lithia,	6.89	6.99	6.94	5.20	5.65
Soda,	.99	.50	.75	.66	1.10
Potassa,	1.45	1.33	1.39	.16	
Water,	.36	.46	.41	.50	.30
	100.63	100.68	100.66	99.38	99.89
Sp. Gr.	3.19	3.185 and 3.201		3.18	3.182

My own three S. G. determinations were made upon quantities of 7.9, 3.6, and 5.5 grammes of mineral, respectively, and show that the true Specific Gravity of *unaltered* Spodumene is a little higher than that hitherto accepted.

A considerable delay having occurred in the publication of this paper since its reading before the Academy, advantage has been taken of the opportunity to incorporate the latest results of other analysts.

Three good analyses of Spodumene have been recently published, on specimens from the following localities: so that I have been anticipated in the publication of the true composition of the mineral.

1. Norwich, Mass., by C. Doelter* (Min. u. petrog. Mittheil., 1878, New Ser., I, 517).
2. Brazil, by C. Doelter (*loc. cit.*).
3. Brazil, by F. Pisani (Compt. rend., 84, 1509: 1877).

The mineral from Brazil is transparent, yellowish-green, resembling Chrysoberyl, but differing in inferior hardness (7), and has a Sp. Gr.=3.16.

	SiO^2	Al^2O^3	FeO	MnO	MgO	CaO	Li^2O	Na^2O	K^2O
1. Norwich	63.79	27.03	.39	——	.21	.73	7.04	1.10	.12
2. Brazil	63.34	27.66	1.15	——	——	.69	7.09	.98	——
3. Brazil	63.80	27.93	1.05	.12	——	.46	6.75	.89	——

By these analyses, Na : Li : : 1 : 15.

In my analyses above given, the alkalies were separated by J. L. Smith's method (ignition with calcium carbonate). The residue of the three alkaline chlorides was carefully purified from adhering traces of magnesia, by repeated precipitation with barium hydrate. The excess of that reagent was removed from the filtrate as carbonate, the solution of the chlorides evaporated to dryness, and the Li Cl separated by digestion in the mixture of ether and alcohol. The lithia was then determined as sulphate, and afterwards, for precaution, as lithium-phosphate, $Li^3\ PO^4$, by repeated precipitation and thorough washing in the usual way. However, the two methods did not produce accordant results, the latter yielding amounts of lithium-phosphate supposed to be pure, which in the two analyses were equivalent to the following per centages:

	I	II
Lithia.	7.43	7.62

The cause of these discrepancies has just been explained by Rammelsberg (Monatsber. der Berl. Akad., 613–631, 1878).

* In his determination of the formula of the mineral from Norwich, with the same result as my own given below, Doelter previously eliminates as impurities over three per cent. out of the percentage stated above, and yet finds an inaccuracy which he attributes to incipient decomposition. This deducted amount he assigns to Orthoclase and Hedenbergite, which have never been found as associates of Spodumene and are therefore of improbable occurrence as impurities. The detection of Killinite in masses, of which analyses are given beyond, explains the green tinge which Doelter naturally refers to Hedenbergite, on the ground of the isomorphous relationship of Augite and Spodumene.

He finds that the precipitate of $Li^3\ PO^4$ carries down a small and variable amount of its analogue, $Na^3\ PO^4$, which always renders the figure for estimated lithia too high.

The differences in these analyses of Spodumene, especially in the amount of oxide of iron, lithia, and the other alkalies, suggest that all the material employed has experienced, to a greater or less degree, incipient decomposition or alteration, attended by the chemical and physical effects already described. Even in my own material, this alteration may be indicated by the presence of water and the excess of alkalies, beyond the amount theoretically required for the protoxides.

Theoretical Constitution.—For the determination of the true theoretical constitution of this mineral, the elementary per centages and ratios have been calculated from the figures of the mean (column marked III), reckoning, Mn, Mg, Ca=2 R^I.

The microscopical examination of the material analyzed, afterwards explained, renders it highly probable that an incipient alteration into Pinite is indicated by the water present; and the proper correction has been made, taking as a basis the amount of water present, and the formula for the Pinite as deduced beyond.

		Ratios. Atomic.	Deduct for Pinite.				Quantivalent.	
Si	29.19	1043	37	1006	4	4	4024	6.3
Al	12.55	459	30	429	1.8	2	1359	2.1
Fe	1.36	24		24				
Mn	.65	12		12	2.2	2	631	1.
Mg	1.07	45		45				
Ca	.32	8		8				
Li	3.24	463		463				
Na	.56	24		24				
K	1.15	29	15	14				
H	.045	45	45					
O	49.86	3116	150	2966	11.9	12		

		Hitherto accepted.
R^I : Al : Si	2 : 1 : 4	1.5 : 1 : 3.75
R : Si	2 : 1	2 : 1
Na (K) : R^{II} (Mg. Ca) : Li	1 : 3: 12	

It has been usual to consider the relation Na : Li, which is here 1 : 9, and, according to other analysts, 1 : 12, varying from 1 : 4 to 1 : 20 ; but it seems proper to group together all the replacing elements in R^I, i. e.

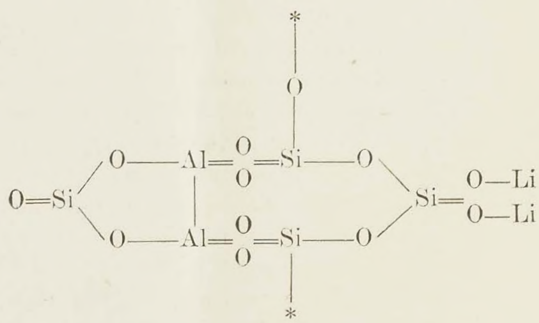
Mn. Mg. Ca. ($=2\ R^I$) + Na. Ka: Li : : 1 : 3.

The corresponding ratio in Pisani's analysis of Spodumene from Brazil is 1 : 6, and it is therefore evident that no definite relationship holds in the replacements within R^I

Spodumene is thus shown to consist of one molecule of the normal silicate of aluminium, plus one molecule of the normal silicate of lithium, and its true formulas must be

		Generally accepted.*
Empirical,	$Li^2\ Al^2\ Si^4\ O^{12}$	$R^6\ Al^8\ Si^{15}\ O^{45}$
Rational	$\begin{cases} (Li.\ Na)^2\ Si\ O^3 \\ \cancel{Al}\ Si^3\ O^9 \end{cases}$	$\begin{cases} 3\ (Li.\ Na)^2\ Si\ O^3 \\ 4\ \cancel{Al}\ Si^3\ O^9 \end{cases}$

This may be graphically represented, but more simply than as given by Dr. K. Haushofer,† adopting the Augite-type, thus :



From my own analyses, the theoretical constitution of the American variety of this mineral may be calculated as follows:

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* Rammelsberg (Handb. der Min. Chem., 423, 1875), Roth (Allgem. u. Chem. Geol., I, 382, 1879), etc.

† Die Const. der natürl. Silicate, 97 (1874).

					Percentages.*
4	Si	112.	equivalent to	Silica	63.75
2	Al	54.6		Alumina	27.25
$\frac{3}{8}$	Mg $\frac{1}{2}$	4.5		Magnesia (or Lime)	1.99
$\frac{1}{8}$	Na	2.9		Soda	1.05
$\frac{12}{8}$	Li	10.5		Lithia	5.96
12	O	192.			100.
		376.5			

In general, it appears that the alumina is sometimes replaced by ferric oxide; the magnesia by lime, ferrous oxide, or oxides of other dyads; the soda by potassa; and the lithia by variable amounts of all the preceding monad and dyad elements.

To recapitulate, it appears to me probable, that the duller color and the inferior lustre, translucency, hardness, and specific gravity of the specimens of the mineral from Norwich and other localities, which have hitherto supplied material for analysis, indicate that in most of these cases the mineral has been somewhat affected by weathering, facilitated both by the easy cleavage of the mineral and by the abundant rifts of the quartz matrix. The loss of a portion of its soluble protoxides—particularly the alkalies—has in most instances increased the content of both silica and alumina in the residue. This slight decomposition has naturally affected the physical characteristics by the differences already described. At both Goshen and Chesterfield the green transparent variety is uncommon, and at Norwich exceedingly rare; while the existence of this decomposition is confirmed by the corresponding effects upon the minerals associated with Spodumene, especially Garnet, Zircon, Triphylite, etc., and by the deposit upon the superficies of the Spodumene crystals, and within all interstices, of black Pyrolusite in delicate tracery, reddish-brown iron-ochre, scales of Autunite and uran-ochre, and a pink substance, the latter at Norwich acting as a characteristic coloring-film upon the Spodumene.

Microscopical characteristics.—On the microscopical examination of a thin section of the unaltered green Spodumene from

* These figures agree closely with those of Brush, (Am. J. Sci., II, x, 370, 1850).

Chesterfield, it appeared under low powers to be in large part clear and colorless, but with its transparency much clouded by a minute granulation (reminding the observer of Olivine) and by abundant cleavage-fissures, some very short and imperfectly parallel, belonging to the imperfect cleavage parallel to the orthodiagonal pyramid, but chiefly in the longer and parallel cleavages of the orthodiagonal and of the prismatic planes. Under a magnifying power of 270 diameters, the granulation is resolved into minute needles of the mineral, closely aggregated in the direction of the stronger cleavage ; but foreign inclusions are rare, consisting merely of tiny orange-brown films and scales of ochre ; of black opaque scales apparently of Hematite ; and, especially along the wider fissures, of yellowish granules, scales, and slender threads of Killinite. Along the fissures, the yellowish material was found to be so abundant as to render the vicinity cloudy, even in a thin section of the purest Spodumene ; this indicates an incipient alteration into Killinite, etc. Muscovite, also, is found either in crystals or clear lakes with sharp rounded outlines ; but in some cases the Spodumene projects into the Muscovite in long fibres, some of which, associated with many ochreous particles, are also enclosed in the Muscovite. Between the crossed nicols, the mineral polarizes decidedly, with bright sheets of color passing into each other.

We have next to consider the interesting series of pseudomorphous minerals which accompany the Spodumene.

I—Cymatolite after Spodumene.

An imperfect analysis of this material from Chesterfield was published in February, 1871 (Am. Chem., I, 300), and that of Aglaite from Goshen, in May, 1879 (Am. Jour. Sci., III, xvii, 398). The statement of the occurrence of this mineral at Norwich (Dana's Syst. of Min., article "Pihlite") is probably a mistake, Prof. Shepard having informed me that he found Cymatolite only at the Barrus locality in Goshen. Profs. Brush and E. S. Dana have recently called attention to a new occurrence of the mineral at Fairfield, Conn. (Am. Jour. Sci., III, xvi, 34, 1878), where they have found, along with "Spodumene in crystals weighing one to two hundred pounds, Cymatolite,

as a result of the decomposition of Spodumene-crystals, sometimes nine inches in width."

Goshen Variety (*Aglaite*).—At the two Goshen localities, I obtained a small supply of a mineral, pseudomorphous after Spodumene, at once suggesting the Cymatolite of Shepard, but presenting some differences in physical character in the variety found on the Barrus farm. It there occurs only as the continuation of the imperfect square prisms of Spodumene (never as a crust upon them), in masses sometimes six or eight inches long, and from $\frac{1}{4}$ to $\frac{3}{4}$ inch square, with usually a sharp line of demarcation across the prism between the two minerals. The structure is micaceous, with the lamination *flat*, very rarely undulating, and always in the plane of the orthodiagonal cleavage of the original Spodumene crystal. The laminæ are brittle, but the thinner scales are flexible, somewhat elastic, and transparent. The mineral is often more or less interlaminated with Muscovite and stained by Pyrolusite. Many of the laminæ, both of Aglaite and Muscovite, project $\frac{1}{4}$ of an inch or more into the gangue at the sides of the crystals, so that the form of the prism is hardly retained in the pseudomorph. Lustre between that of silver and satin. Color, white. Feel, soft. Hardness=1.5. Sp. Gr.=2.753 (determined on 6 grammes).

The specific gravity in this case, as well as in all others subsequently given in this paper, was determined on the mineral in coarse powder, in distilled water at 62° F., generally after previous digestion on a steam-bath until the complete expulsion of all air-bubbles.

I am also indebted to the kindness of Prof. C. U. Shepard for a small fragment (0.7 gramme) from one of the specimens originally found by him, which, besides presenting physical characteristics identical with those described above, was found to possess a specific gravity of 2.726.

Chesterfield Variety.—At the Chesterfield locality, this pseudomorphous material is far more abundant, and indeed predominates in quantity over that both of Spodumene and of all other products of alteration. The sizes of these pseudomorphs have been already described. Here the structure is intermediate be-

tween micaceous and fibrous, with a strong wavy tendency of the foliation, on the surface of fracture, especially in the thicker crusts with longer fibres. In the smaller crystals, the plane of foliation is usually at right angles to the faces of the Spodumene, and the folia therefore radiate from a central plane in those crystals which are completely altered ; but in the larger ones, within a thin radiating crust of this kind, the folia of the pseudomorph generally and mainly conform to the central plane—that of the orthodiagonal cleavage of the Spodumene,—and a parallel foliation often results, with a complete disappearance of the wavy tendency along the axis of the pseudomorph. When a core remains in the smaller crystals, it is very often, if not generally, found to consist of the blackish-green Pinite (Killinite), while in the larger crystals the core consists of bright-green to greenish-white or white Spodumene, often with the dark Pinite within an inch or so of its termination, or forming a thin layer at various places next to the white pseudomorphous crust. Most of these phenomena are shown in Fig. 1, Plate XIII, a sketch (natural size) of the cross-fracture of one of the partially altered crystals. In this, a remnant of unaltered Spodumene is presented in the dark core, of a greenish-grey color, retaining the three cleavages indicated by the lines, and bordered, especially near the lower angle of the core, by a thin film of blackish-green Killinite. The whole is enveloped by the crust of wavy white Cymatolite, with satiny lustre, which also traverses the core in thin seams.

The greenish-yellow Muscovite, which abounds in the vein, is commonly intercrystallized in the larger pseudomorphs, in scales and films, sometimes so intimately that the two materials are indistinguishable by the eye, and a yellowish color is produced. The more slender of the pseudomorphous crystals are often found penetrating the coarse masses of Beryl, but the latter is never enclosed ; while the black octahedra of Oerstedite are frequently found, not only implanted on the outer planes of these pseudomorphs, but often enclosed in the above yellow mixture. Many of the longer pseudomorphous prisms are found to be more or less flattened, distorted, twisted, or bent into decided arcs, or with their terminations squeezed into a wedge or bladed shape. At this locality there is a remarkable want of adherence

between the pseudomorphous crystals and the quartz-gangue, so that a slight blow of the hammer releases them in an uninjured condition.

Hardness, 1.5 to 2. Specific Gravity, 2.700 (determined on 5.7 grammes of coarse powder), 2.696 (determined on 5.5 grammes, in a lump, long digested to expel air). Lustre intermediate between silver and satin, but seeming to approach the latter, on account of the fibrous texture. Color, white to yellowish, also often stained by films of Ochre or Pyrolusite. Laminæ brittle, and only separable with difficulty, or not at all in the larger compact masses. Translucent on thinner edges. Feel, soft.

Pyrognostic Character.—In platinum forceps, it fuses on very thin edges (6), and the surface of the splinter becomes covered with a white and translucent blebby enamel. A fragment, moistened with solution of cobaltic nitrate, gives the alumina reaction without difficulty. In a matrass at high temperature, it yields a little water, and a small amount of ammonia, indicated by a feeble odor but distinct reactions with test papers, etc. In borax bead, it dissolves readily, with effervescence and in large quantity, to a clear bead, with the yellowish iron reaction while hot; gradually displays a siliceous skeleton; and at saturation becomes clouded by silica and bubbles. In phosphoros-salt, as in borax, but with immediate formation of the siliceous skeleton. Insoluble in acids.

Analyses of Cymatolite.—In the columns below are given the results of four analyses of the common wavy variety of this mineral, which was found in abundance at the Chesterfield locality.

VI and VII—Cymatolite from Chesterfield. Analysis in duplicate of the average material derived from a mixture of fragments of about forty different crystals, white and yellowish-white in color, taken at random.

VIII—Mean of the foregoing two analyses.

IX—Cymatolite from Chesterfield. Analysis of a slice across a complete pseudomorphous prism, of the radiated fibrous structure and white color, about an inch in diameter. Apparently it was completely altered to pure Cymatolite, but the increased amount of lithia in the analysis *may* indicate the presence of

over three per cent. of unaltered Spodumene, probably disseminated along the core.

X—Cymatolite from Chesterfield. Analysis of a fragment of the compact white variety, from a large pseudomorph about nine inches in diameter.

CYMATOLITE (CHESTERFIELD).

	VI	VII	VIII (Mean of VI & VII).	IX	X
Silica,	58.57	58.59	58.58	59.60	58.71
Alumina,	22.25	22.32	22.28	22.97	24.00
Ferric Oxide,	1.79	1.75	1.77	1.63	1.39
Manganous Oxide,	.15	.15	.15	.45	.11
Cobaltous Oxide,	.02	trace	——	trace.	——
Magnesia,	.49	.41	.45	.31	.27
Lime,	.95	.91	.93	.35	.51
Lithia,	.10	.09	.10	.26	.21
Soda,	9.17	8.99	9.08	7.83	7.38
Potassa,	4.48	4.47	4.48	5.14	4.67
Water,	2.04	2.12	2.08	1.73	1.80
Nitrogenous Organic Matter,				.32	.62
	100.01	99.80	99.90	100.59	99.67

In IX, on the ignition of 8.65 grammes with soda-lime, the organic matter was found to yield 0.02 per cent. of ammonia (NH^3). In this determination, as also in the similar one applied to Killinite, the possibility of absorption of the ammonia from laboratory vapors was eliminated by using specimens never so exposed, and a "blank analysis" carried on at the same time supplied the small correction necessary for ammonia introduced through the distilled water and reagents employed. It appeared to be a necessary precaution to select the variety of

material mentioned above, in order to establish its uniformity of composition, notwithstanding its pseudomorphous origin.

The following analyses were made upon materials from the two localities found in Goshen.

XI—Cymatolite from the more easterly locality, N. W. of Goshen Centre.

Common wavy and yellowish material, in part finely granular, in irregular pseudomorphous prisms, generally stained by Pyrolusite. The material was only with difficulty selected in sufficient purity for analysis. It resembled that of the Chesterfield locality.

XII—Cymatolite from the Barrus farm, west of the foregoing. The micaceous and brilliant rare white variety (Aglaite), in a perfectly pure state.

XIII—Cymatolite, average composition, as deduced from all my preceding analyses (VIII, IX, X, XI, and XII), on the material obtained from the three localities in Chesterfield and Goshen.

	XI Goshen. Wavy Yellow Cymatolite.	XII Goshen. Aglaite.	XIII Average of all analyses of Cymatolite.
Silica,	58.51	58.11	58.70
Alumina,	21.80	24.38	23.09
Ferric Oxide,	.85	1.66	1.46
Manganous Oxide,	.29	.18	.24
Cobaltous Oxide,	trace	——	——
Magnesia,	1.44	.75	.64
Lime,	.84	.48	.62
Lithia.	.19	.09	.17
Soda,	6.88	2.57	6.75
Potassa,	6.68	8.38	5.87
Nitrogenous Organic matter,	.44	.43	.45
Water,	1.96	2.58	2.02
	99.88	99.61	100.01

In the determination of loss by ignition in Aglaite (XII), it was found that this micaceous and porous mineral obstinately retained some hygroscopic water above 100° C.

By long-continued heating, it lost—

At 110° C, 0.23 per cent (moisture).

At red heat, 3.01 " " (water of combination and organic matter).

The corresponding results, obtained on the fragment of original Cymatolite received from Prof. Shepard, were as follows :

At 110° C, 0.37 per cent (moisture).

At red heat, 3.28 " " (water of combination and organic matter).

The sum of the latter figures closely approaches the result reported by Prof. Burton (3.78 per cent.), which was obtained (as he has informed me) from the mineral dried at 100° C.

It may here be added, that the analytical figures given in my preliminary notice of the composition of this mineral (Am. Chem., I, 300, 1871),* and there temporarily assigned to Pihlite in accordance with Dana's view (Syst. of Min., 455, 1869), are too imperfect for further consideration.

Theoretical Constitution.—From the average composition of the mineral, given in column VII, the following elementary constitution and ratios may be deduced, reckoning

Mn, Mg, Ca=2 R^{I}.

	Percentages.		Ratios: Atomic.		Ratios: Quantivalent.		
Si	27.39		978	12.	3912	24.	8
Al	12.31	451	469	5.7	1407	8.6	3
Fe	1.02	18					
Mn	.19	3					
Mg	.38	16					
Ca	.44	11					
Li	.08	11	481	5.9	481	3	1
Na	5.01	218					
K	4.88	125					
H	.23 { basic	67					
	{ as aq.		163	2.	163	1	$\frac{1}{3}$
O	47.63		2977	36.5			

* Afterwards quoted in 2d App. to Dana's Min., 44, 1875, and Roth's Allg. u. Chem. Geol., I, 382.

To confirm the uniformity of these relationships, the atomic ratios have been further calculated in the same way from four of the individual analyses.

	VIII		X		XI		XII	
Si	976	12.2	987	12.1	975	12.2	969	12.
Al (Fe)	456	5.7	484	6.	436	5.5	496	6.1
Na (H, K)	474	6.	444	5.5	546	6.8	458	5.7
O	2954	37.	2980	37.	2956	37.	2988	37.
H (as aq.)	161	2.	161	2.	161	2.	161	2.

The atomic ratios of the elements which constitute R^I, in these analyses, are given in the following table.

	VIII		X		XI		XII	
Mg, Ca	60	3	34	2	110	5	62	3
Na	293	15	238	13	222	10	83	4
K, Li	102	5	113	6	155	7	184	10
H (basic)	19	1	59	3	59	2	129	7

From these figures, it may be inferred that the proportion of the several elements is somewhat indefinite and irregular, and that a sufficient complement of basic hydrogen is always present. The amount of sodium diminishes through the varieties to the lowest degree in Aglaite (XII), in which both potassium and hydrogen rise to the maximum ; and that is the variety which possesses the physical characteristics most akin to those of the potash-bearing hydromicas.

From the atomic ratios

$$\begin{array}{ccccc} R & : \ \bar{\mathbf{R}} & : \ Si & : \ O & : \ Aq. \\ 6 & 3 & 12 & 37 & 1 \end{array}$$

the formulas* of Cymatolite, empirical and rational, are found to be those of a normal silicate—

---

* According to the old system—

$$(\tfrac{1}{3}\ (\tfrac{1}{2}\ HO + \tfrac{1}{2}\ KO,\ Na\ O)^3 + \tfrac{2}{3}\ \bar{Al}\ O^3)\ 3\ Si\ O^2.$$

From my analysis of Aglaite, P. Groth (Zeits. f. Kryst. u. Min., 111, 1878) deduces the formula—

$$(H,\ Na,\ K)^{16}\ Al^6\ Si^{24}\ O^{65}.$$

$$H^2 \, R_I^6 \, \mathbf{R}^3 \, Si^{12} \, O^{37} \text{ or } H^2 \, (H, Na, K)^6 \, Al^6 \, Si^{12} \, O^{37}$$

$$= 3 \left\{ \begin{array}{lll} Na^2 & Si & O^3 \\ \mathbf{Al} & Si^3 & O^9 \end{array} \right\} + Aq.$$

This yields the following calculation for the theoretical percentages in the constitution of the mineral.

				Calculated.	Found.
12 Si	336		Silica	58.46	58.70
6 Al	163.8		Alumina	24.99	24.55
6 Na	138.	equivalent to	Soda	15.09	16.31
2 H	2.		Water	1.46	
37 O	592.				
	1231.8			100.	99.56

In view of the results obtained by so careful an analyst as Prof. Burton, and of the fact that his analysis and formula have been for over ten years associated with the name "Cymatolite," it seemed to me at first most judicious to attach a new name* to the new constitution of my own abundant material. However, since I have received from Prof. Shepard a fragment from an original specimen of his own collection, its identity with mine in all physical characteristics, seems to justify the application of the name, Cymatolite, to my own material as well. And yet it may be convenient to retain the name I proposed, *Aglaite*, (from ἀγλαὸς, brilliant) for the Barrus farm variety of Cymatolite. As already explained, this differs from the rest, both in the constitution of the protoxides, and in possessing a more brilliant silvery-white lustre and color, and generally a flat micaceous instead of a "wave-like" structure—a variety, therefore, to which the etymology of the name, Cymatolite, is not appropriate.

Cymatolite appears to be a hydrous bisilicate, which, excluding all but basic hydrogen, possesses the essential constitution of Spodumene. The character of the alteration may be simply stated.

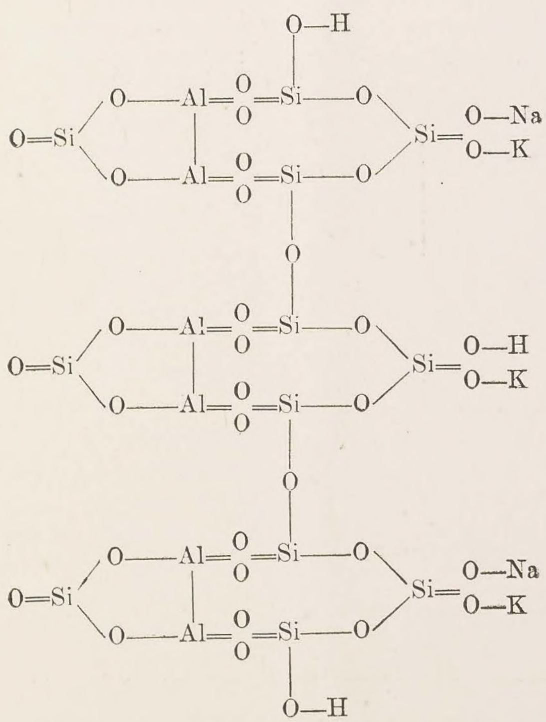
In 3 molecules of Spodumene, the monad element has been

* Engineering and Mining Journal, April 7, 1877.

replaced by Na^2, K^2 and H^2, in various mutual proportions, and 1 molecule of aq. added, with the result :

Spodumene.	Cymatolite.
$(Li, Na)^6\ Al^6\ Si^{12}\ O^{36}$	$H^2(H, Na, K)^6 Al^6\ Si^{12}\ O^{37}$
or	
$3 \left\{ \begin{array}{r} (Li, Na)^2\ Si\ O^3 \\ \cancel{Al}\ Si^3\ O^9 \end{array} \right.$	$3 \left\{ \begin{array}{r} (H, Na, K)^2\ Si\ O^3 \\ \cancel{Al}\ Si^3\ O^9 \end{array} \right\} + aq.$

The latter formula may be represented graphically as follows, and consists, as will be seen, of a closed combination, saturated within itself.



Microscopical Characteristics.—Under the microscope, the Aglaite of Goshen, instead of being made up of continuous sheets, as it appears to the eye, presents everywhere an irregular

fibrous network, an interwoven congeries of needles, scales, and blades, some of which have parallel sides, and are crossed obliquely by minute planes (× 175), which suggest a cleavage structure. There are also here and there a few more distinctly crystallized blades of Muscovite, with parallel sides, which seem to lie across the general direction, but which never present good terminations. Among these blades are minute oblong bodies, often in groups, which under a sufficiently high power are also found to be perfect and doubly-terminated crystallized scales. Their length varies from 0.0019 to 0.0114 mm. Many are scattered through the material, having evidently crystallized between the laminæ, and others are gathered in groups of considerable numbers. There are also numerous minute ochreous granules dispersed throughout. With strong illumination, interference fringes, with bright colors, are produced by the fine fibrous structure of the Aglaite. Between the crossed nicols of the polariscope, the mineral possesses a strong double refraction, with colors varying from brownish yellow, through purple, into bright blue.

The mineral from Chesterfield also presents a fine fibrous structure, somewhat curved, and without any interference fringes. Muscovite is occasionally distinguishable, either in rectangular blades or minute crystalline groups, sometimes 0.4 mm. in length: its presence, as well as that of occasional remnants of unaltered Spodumene in tiny fibres, seems to throw light on the excess of protoxides found in the analyses. Ochreous granules are not uncommon, and the existence of ferric oxide or hydrate in this accessory condition indicates at least that a portion of it should not have consideration in the formula.

The fibres of Cymatolite seem to spring from the terminal edges of those of the Spodumene, and form a continuation of their structure: so that it is evident that the process of alteration has most rapidly and favorably attacked the Spodumene from the ends of its fibres. Between the crossed nicols, the fibres present the usual strong double refraction and vivid colors, while the grains of unaltered Spodumene are feebly illuminated with colors varying on rotation from light brown to bluish gray. In a thin section made from a sliced cross-section of an entire pseudomorphous crystal, about an inch in diameter, of which the

corę was composed partly of both Killinite and Spodumene, some further interesting observations were made. Near the outer margin of the section, the fibres of Cymatolite, lying at right angles to the contour of the crystal, were mostly parallel and undisturbed. But in approaching the core, sometimes the bundles of fibres were strongly curved, and sometimes completely dislocated into a confused mass of scales. Near the junction-line between the Cymatolite-crust and the core, the same curved bundles of fibrous blades were often observed. Outwardly they abutted perhaps against some one of the plates of Muscovite (which always have been formed and lie parallel to the axis of the Spodumene-crystal): in such a case the plates of Muscovite were seen to be partly dislocated, and their laminæ shoved successively past each other *en echelon*. Inwardly their apices were directed against the yet unaltered core—like a forest of spears thrust against a fortress-wall. Some of these apices are seen to have been insinuated within the crevices of the Spodumene (or Killinite), apparently leaving a minute sieve-like passage between the serrated or drusy margin of the Cymatolite and the cracked surface of the Spodumene.

At first it had been concluded, from the many evidences of distortion which the pseudomorphs present, that these were merely the results of ordinary mechanical pressure, produced in this granite-vein—as certainly in many others tilted at high angles—by a settling of its contents in the direction of the dip of the vein, and by considerable internal motion. Greater familiarity with the latter phenomenon in other localities has called attention to its other accompanying results—such as slickensides, minute downward dislocation of crystals (as in long prisms of Beryl and Tourmaline), or folding of mica plates, by unequal or sudden pressure, etc.—*which appear to be completely wanting in this case.*

Now, the atomic volume of the triple molecule of Spodumene is about 355, but it rises to 451 in Cymatolite. It has therefore occurred to me that the pressure, which produced the bending, twisting and flattening of crystals, and the apparent squeezing or pinching of their terminations, may be possibly attributed to an entirely different cause. These facts may present a novel and interesting illustration, on a remarkably large

scale, of the phenomena of a crystallization attended by absorption of water and alkalies, and by great consequent expansion within a confined space. The volume of that part of the granite-vein at Chesterfield Hollow which has been excavated, comprises perhaps two or three hundred cubic yards of rock, and its original content of Spodumene must have amounted to several tons, a quantity sufficient, during alteration and expansion, to have produced an enormous pressure. On the one side, this mechanical force of expansion has hastened the process of alteration, both by the rupture of the superficies of the Spodumene, and by the production of the minute sieve-like space, which has apparently supplied the principal channel for the solutions which effected the pseudomorphous change. Outwardly, great pressure was at first exerted against the quartz-matrix, producing, as with the expansion of type-metal in a mould, a sharp impression upon the Cymatolite-crust—especially in the smaller prisms—of the finest lines of the cast of the Spodumene, and often, around the larger crystals, also crushing and rupturing the quartz, leaving it seamed by the present innumerable little rifts. This was probably followed by a subsequent contraction of the two materials, by loss of temperature and moisture, to which may be due the present slight adherence between the crystals and their gangue. Also, within the pseudomorphous crust, the same pressure brought about a bending of fibres and dislocation of scales, which resulted in the wavy structure to which Cymatolite owes its name, and which, being more than a mere accident, but in most localities essentially connected with the genesis of the mineral, imparts to that name a peculiar appropriateness.

The irregular transmission of pressure through the partially crushed and ruptured quartz-matrix, appears to have resulted in the bending, flattening, and common distortion of the crystals.

Again, in those crystals in which the more rapid process of alteration from a termination has progressed so far along the axes as to have produced blade-like cores, retaining the orthodiagonal cleavage of the parent Spodumene, the terminations are found to be flat or pointed, not merely in most cases by being pinched together by a pressure from without, but in many instances, perhaps, by the expansion and forcible protrusion of the bladed cores.

In the Goshen variety of the mineral, Aglaite, the pseudomorphous material was never formed as an enveloping crust, but entirely in the direction of the axes of the prisms. The density and toughness of the matrix would appear generally to have allowed the commencement of the attack only from the terminations; and the rapid progress of the alteration in the direction of the axis (as also in less degree along the cores of the Chesterfield prisms) seems to have been caused by the more ready wedging up of the Spodumene in its easiest plane of cleavage, the orthodiagonal, by the pointed ends of the Cymatolite blades. As fast as produced at the sharp alteration-line (marked in Fig. 2), the minute spiculæ and scales of Cymatolite hardly attained a length of a few hundredths of a millimetre before they were thrust aside in the same plane. The pressure was exerted mainly in that plane; laminæ were projected outwardly into the granitic gangue, perhaps somewhat plastic and yielding (resulting in the present lateral adherence of the altered prisms); and the laminæ thus retained the flatness, without crumpling, peculiar to Aglaite.

II—Killinite *after Spodumene.*

A second pseudomorphous material of the Pinite family, apparently Killinite, was found, frequently but in limited quantity at Chesterfield Hollow, and quite rarely in the Huntington vein. It sometimes occupies the entire core of some of the smallest Cymatolite pseudomorphs, in a dark mass, perhaps 1 to 2 inches in diameter. But ordinarily it constitutes only an outer layer of the Spodumene core, intermediate between that mineral and the enveloping crust of Cymatolite, in some of the larger crystals: in such cases it is rarely continuous, but usually occurs in isolated spots or sheets, presenting often a broken or wavy dark line along the fracture-section of the outer edge of the Spodumene-core. The contiguous portion of the Spodumene, though retaining its white color, is also found to show alteration, both by its yield of water, when heated in a closed tube, and by the exhibition under a pocket-lens, of very minute dark films of Killinite in a delicate net-work.

The purest Killinite presents the following characteristics.

Texture foliated, with the cleavages of Spodumene, but less perfect.

Hardness, 3.5. Specific Gravity, 2.623, (in coarse powder), 2.644, and 2.652 (in lumps).

Lustre, dull and greasy on irregular surfaces, to weak vitreous, or sometimes strongly vitreous, on the planes of orthodiagonal cleavage of the original Spodumene. Color, greenish-gray to olive-green, ranging, however, from greenish-black to greenish-white, the latter along the border next the unaltered Spodumene. Streak and powder white, slightly greenish. Opaque, only slightly translucent on thin edges. Fracture uneven, as in Spodumene. Feel, greasy. When breathed upon, it gives off a faint argillaceous odor.

Pyrognostics.—In the platinum forceps or on charcoal, it becomes snow-white and fuses along thin edges (fusibility 5.5), without visible intumescence, to a white and translucent blebby enamel. A fragment whitened but not fused, and then moistened with cobaltic nitrate, yields a feeble alumina reaction. In matrass, it darkens to an ash-gray, in part reddish, and gives off immediately, at a low red-heat, much water and a decided odor of ammonia, with the usual reactions for that substance. With borax and phosphorus salt, it furnishes a slight effervescence, a feeble reaction for iron, and a siliceous skeleton.

Analysis of Killinite.—The chemical composition of Killinite is presented in the following analyses.

XIV—Olive-green Killinite, from Chesterfield Hollow, Mass. Analysis by myself. S. G.=2.623. Also, for comparison, selected out of many discordant analyses—

XV—Killinite from Killiney Bay, Ireland. Analysis by Lehunt & Blythe (Thomson's Min., I, 330). Different analysts report S. G.=2.56—2.71, in the Killinite from this locality, probably varying according to the intermixture of the unaltered Spodumene.

	XIV.	XV.
Silica,	46.80	47.93
Alumina,	32.52	31.04
Ferrous Oxide,	2.33	2.33
Manganous Oxide,	.04	1.26
Cobaltous Oxide,	.04	—
Magnesia,	.48	.46
Lime,	.77	.72
Lithia,	.32	—
Soda,	.78	—
Potassa,	7.24	6.06
Water,	7.66	10.
Nitrogenous Organic Matter,	1.14	—
	100.12	99.80

Also, on ignition of 2.79 grammes of the Pinite from Chesterfield with soda-lime, and on addition of platinic chloride to the distillate, 65 milligrammes of ammonium platino-chloride were obtained, which correspond to 0.18 per cent. of $N H^3$, derived from the organic matter. The percentage of lithia in the above analysis, I think, certainly represents over four per cent. of Spodumene remaining unaltered: so that on making the proper reductions, the atomic ratios may be calculated as follows, reckoning Fe, Mn, Mg, Ca=2 R^I.

		Raised to 100 pr. ct.	Per cent.			Atomic Ratio.		
$Si\ O^2$	44.07	46.54	Si	21.72		776	5	5
$Al^2\ O^3$	31.35	33.10	Al	17.61		645	4.1	4
Fe O	2.30	2.43	Fe	1.89	34			
Mn O	.04	.04	Mn	.03	1			
Co O	.04	.05	Co	.04				
Mg O	.48	.51	Mg	.31	13	314	2	2
Ca O	.77	.81	Ca	.58	15			
Na^2 O	.76	.80	Na	.59	26			
K^2 O	7.24	7.64	K	6.34	162			
H^2 O	7.65	8.08	H	.89		890	5.7	6
			O	50.		3125	20	20
		100.						

Theoretical Constitution.—The following atomic relationships may be thence deduced, reckoning R^{II}=2 K.

$R^{II} : K$	$R^{I} : \mathbf{R} : Si : H$	$Si : H^2 O$
$1 : 1.5$	$1 : 1 : 2.5 : 2.9$	$1 : 0.6$

This corresponds to the formula for the half-silicate, which Rammelsberg writes—

$$H^6\ K^2\ \cancel{Al}^2\ Si^5\ O^{20}.$$

if all the hydrogen be basic. Or, after his other plan, with no basic hydrogen, it may be written—

$$\left\{\begin{matrix} 2\ R\ \ \cancel{Al}^2\ Si^5\ O^{17} + 3\ aq. \\ 3\ K^2\ \cancel{Al}^2\ Si^5\ O^{17} + 3\ aq. \end{matrix}\right\}$$

But in my opinion, for a reason stated beyond, it is probable that only one-third of the hydrogen is basic, and that the true empirical formula should read—

$$H^2\ K^2\ \cancel{Al}^2\ Si^5\ O^{18} + 2\ aq.$$

or

$$R^{16}_{I}\ Si^5\ O^{18} + 2\ aq. = \left\{\begin{matrix} 2\ R^2\ Si\ O^3 \\ 3\ R^4\ Si\ O^4 \end{matrix}\right\} + 2\ aq.$$

i. e., two molecules of the normal and three of the half-silicate, plus two of water.

Killinite thus appears to bear a close chemical relationship to Iolite in its forms altered by hydration, *e. g.* Fahlunite, Chlorophyllite, etc., and to possess the rational formula,

$$2\left\{\begin{matrix} K^2 & Si & O^3 \\ \cancel{Al} & Si^3 & O^9 \end{matrix}\right\} + 3\left\{\begin{matrix} (H, K)^2 & Si & O^4 \\ \cancel{Al}^2 & Si^3 & O^{12} \end{matrix}\right\} + 2\ aq.$$

The theoretical percentage composition, calculated from the empirical formula, will be as follows:

5 Si	140.	equivalent to	Silica	45.92
4 Al	109.2		Alumina	31.40
2 K	78.2		Potassa	14.42
2 H (basic)	2.		Water (basic)	2.75
4 H	4.		" (aq.)	5.51
20 O	320.			
	653.4			100.

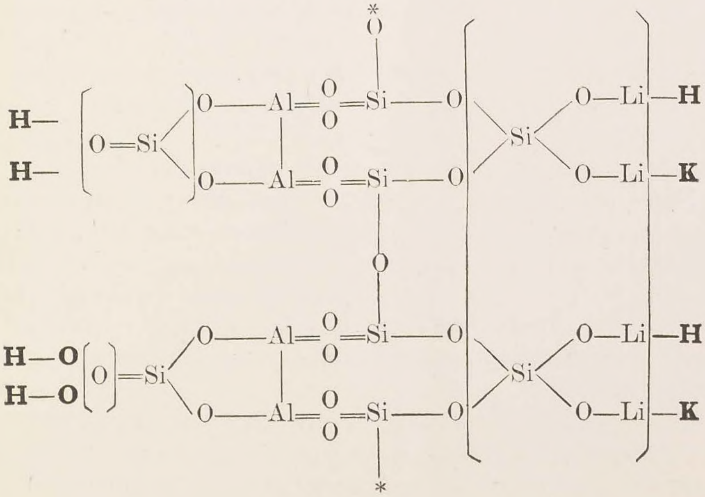
Its genetic relationship to Spodumene may be simply represented as follows. In two molecules of Spodumene,

$$Li^4 \ \cancel{Al}^2 \ Si^8 \ O^{24}$$

the four atoms of lithium have been replaced by (H^2 K^2,) three molecules of silica, (3 Si O^2) have been removed, and two molecules of water of crystallization, (2 H^2 O), have been added by the solution of alteration : leaving that which therefore seems to me the true empirical formula for Killinite,

$$H^2 \ K^2 \ \cancel{Al}^2 \ Si^5 \ O^{18} + 2 \ aq.$$

The following represents these changes graphically, the removed constituents being enclosed in brackets, and those added being put in heavy letters.



The foreign Killinite has only been found in Ireland, on the shores of Killiney Bay, at Killiney and Dalkey, near Dublin, in granite-veins traversing mica-schist, and with Spodumene, Garnet and Tourmaline as its associates. The imperfect crystallization of the Spodumene at that locality sufficiently accounts for the hesitation with which the theory of the derivation of the Killinite from that mineral has been gradually accepted. This new American occurrence, however, establishes the certainty of that mode of origin.

Microscopic Character.—On a microscopical examination of a thin section, under low powers, the Killinite of Chesterfield is found to present a slightly greenish-yellow color, with apparently the structure of Spodumene. Under higher powers, the Killinite appears to be largely concentrated as a vein-like material along the stronger cleavage-fissures of the pseudomorph, and exhibits a minute granulation and thready structure, sometimes with comb-like projections on each side along the other cleavage planes of the parent mineral. It is always rich in free Ochre, which substance serves *in the thin section* as a brownish-yellow coloring material. This, however, is often abundantly separated in nearly opaque reddish-brown flocks at the line of contact between the Cymatolite and Killinite.

This fact, and the presence of organic matter, suggest that the entire content of iron in this mineral may not exist in chemical combination in the main pseudomorphous substance present, and may not be essential, but may have been in part rejected, during the alteration of the Spodumene, in a ferrous combination with an organic acid. This seems to have been diffused as a greenish coloring material, subsequently oxidized during the artificial preparation of the thin section under examination. If this conclusion be true, a part of the atomic fraction of iron in the calculation of the ratio should have been disregarded; but, aside from replacing it by an equivalent of basic hydrogen, I think the calculation and formula would remain unaffected.

When the line of contact between the Killinite and Cymatolite is examined where it crosses the fibration both of the Killinite and of the Cymatolite (*i. e.*, transversely to the axis of the

prism), on the one side of it appear the rigid fibres of Killinite, straight and parallel, and, on the other, end to end, the curved needles and blades of the more flexible Cymatolite. But along that portion of the line, at the sides of the prism, where it runs parallel to the fibres of Spodumene or Killinite, it displays minute but abundant rounded indentations into the mass of the latter minerals, now occupied by the ends of Cymatolite-needles, in projecting bundles, or sometimes mixed in great disorder.

These indentations are also represented in the drawing (Fig. 2, Plate XIII): K—K is the Killinite, retaining the fibrous texture of the original Spodumene, C is the Cymatolite, and *a—a* the irregular line of contact between the two minerals. Along this line, many of the blades of Cymatolite display their terminations still perfect, being more recently formed and as yet sheltered from the pressure. The ends of many others are broken off bluntly or more or less obliquely, and the fragments appear here and there along the contact-line and even in the Killinite, as at *b*; while several blades have been crushed up into a mass of irregular scales, at *c*, by a side-thrust from the left. The dark points scattered about are particles of ferric hydrate. The drawing was made under the microscope, and with the help of the camera lucida, upon a thin cross-section of an altered crystal, and at a magnifying power of 1002 diameters, (reduced to 617 at the size of the wood-cut).

III.

Albitic Granite after Spodumene.

The pseudomorphs most conspicuous by size, even more so than those of Cymatolite, consist of a vein-granite, made up of Muscovite, Albite, and Quartz, in varying proportions, even within the same pseudomorph, with Manganese-Garnet, Oerstedite, Beryl, etc., occasionally interspersed.

The large Cymatolite-columns generally pass at one end into mixtures of this character, and enormous masses of one or two hundred weight have thus been formed. They consist of an aggregation of perhaps only two or three pseudomorphs of this kind, rudely but in places distinctly shaped, each from several inches to nearly a foot in diameter, and from one to nearly three feet

in length. Various transitions were observed in the disposition of these materials, such as huge pseudomorphs, of which a large core consisted of a coarse aggregate of mica-crystals, with an outer crust one or two inches thick, in some cases of Cymatolite, and in others of grayish-white Quartz.

IV.

Muscovite after Spodumene.

Many pseudomorphs were found in the Chesterfield vein, which consist in large part or entirely of a greenish-yellow Muscovite with peculiar greasy lustre. In fact all stages of intermixture with Cymatolite were observed, from the almost pure pseudomorphs in the latter mineral, in which Muscovite occurred only in minute or even microscopic scales, lying mostly parallel to the axis of the crystal—to others, in which the mica was so abundant as to have imparted a yellow or greenish color to the mixture—and at last to micaceous pseudomorphs, perfectly free from Cymatolite, retaining the form and superficial striation of the Spodumene even to the terminations, though the latter are in general more or less flattened in form and distorted. All these varieties of intermixture appear to be rather the results of intercrystallization than of alteration of either one of the pseudomorphous minerals into the other. The suddenness of the change of conditions which produced the one or other material is often illustrated by prisms, which consist of pure Cymatolite in one part of their length, and of Muscovite generally toward their terminations, with a sharp line of demarcation between the two.

Another kind of pseudomorph in Muscovite, less perfect in form, is a variety of those described under III, in which the mica may largely predominate over its associates. In the former kind, the mica tends to occur in continuous enveloping scales, parallel to the axis of the crystal; while in the latter the mass is always made up of imperfect crystals and flakes of mica, generally from one-half to two inches in diameter, lying confusedly in all planes, and producing a coarse granular structure. The former traverse the smoky quartz in slender and perfect prisms, sometimes six inches to a foot or more in length, and from one

or two inches down to one-eighth of an inch in diameter, but generally bent. The coarser pseudomorphs of the second kind are often of enormous size, as described under III.

At the Barrus locality in Goshen, the Aglaite and Muscovite are intercrystallized in similar ways. The laminæ of the Muscovite also are continued into the gangue, and assist in producing the strong adherence of the latter to the altered prisms.

Genetic Relationships.—The nature of the chemical reactions connected with the genesis of the pseudomorphs in Muscovite and in Albite, may be understood from a consideration of the following published analyses of the minerals from this region :

XVI—Muscovite from Goshen. S. G. 2.859.
Analysis by C. F. Rammelsberg (Zs. G., xix, 400).

XVII—Muscovite from Goshen, rose-colored.
Analysis by Mallet (Am. J. Sci., II, xxiii, 180, 1857).

XVIII—Albite from Chesterfield.
Analysis by Stromeyer (Untersuch., 300).

XIX—Albite from Chesterfield.
Analysis by Laurent (Ann. Ch. Phys., lx). Both these Albites were *probably* the Cleavelandite from Clark's Ledge.

	Muscovite			Albite	
	XVI	XVII		XVIII	XIX
Fluorine,	.52				
Silica,	47.02			70.68	68.4
Alumina,	36.83			19.80	20.8
Ferric Oxide,	.51		Fe O,	.11	.1
Manganous Oxide,	1.05				
Magnesia,	.26				
Lime,				.23	.2
Lithia,	} .30	.64			
Soda,		.99		9.06	10.5
Potassa,	9.80	9.08			
Water,	3.90				
	100.19			99.88	100.

Atomic Ratios.

	(Fe, Mn, Mg=2K)		
H : K	1.6 : 1		
H, K: ~~Al~~, ~~Fe~~ : Si	1.9 : 1 : 2.1	Na: ~~Al~~ : Si	2 : 1 : 6

The Muscovite from this locality is thus determined as a half-silicate,

$$\mathrm{R_I^2\ \cancel{Al}\ Si^2\ O^8} = \begin{cases} \mathrm{R^4\ Si\ O^4} \\ \mathrm{\cancel{Al}^2\ Si^3\ O^{12}} \end{cases}$$

The Albite appears to be the sesqui-silicate—

$$\mathrm{Na^2\ \cancel{Al}\ Si^6\ O^{16}} = \begin{cases} \mathrm{Na^4\ Si^3\ O^8} \\ \mathrm{\cancel{Al}^2\ Si^9\ O^{24}} \end{cases}$$

It is probable that there has commonly occurred a splitting up of two molecules of the bi-silicate, Spodumene, by a simple transference of two atoms of silica from one to the other, into one molecule of Muscovite and one of Albite, the lithium being replaced by potassium or sodium out of the solution during this change. This may be represented—

$$\begin{array}{ccccc} \text{2 Mol. Spodumene} & & \text{1 Mol. Muscovite} & & \text{1 Mol. Albite.} \\ \mathrm{R_I^4\ \cancel{Al}^2\ Si^8\ O^{24}} & = & \mathrm{R_I^2\ \cancel{Al}\ Si^2\ O^8} & + & \mathrm{Na^2\ \cancel{Al}\ Si^6\ O^{16}} \end{array}$$

It is further possible that the formation of the great masses of Muscovite has been in large part due merely to the separation of two molecules of silica from a molecule of Spodumene, the silica thus isolated being deposited as quartz within many of the pseudomorphs.

Microscopic Structure.—In a thin section of Spodumene containing Muscovite, the latter appears under a low power as clear rounded glassy lakes; while in some cases the Spodumene is prolonged into slender threads, projecting into the mica parallel to the bladed laminæ of the latter.

V.

Albite after Spodumene.

This form, generally intermixed with a little Muscovite and less quartz, is a mere variety of III, much rarer than IV, and always with rather indistinct outlines and terminal faces obliterated.

VI.

Quartz after Spodumene.

The pseudomorphs in quartz are very rare, sometimes six to nine inches in length, with the original faces and striations of

the crystal sharply defined, but with the termination obliterated. They are more or less intermingled with scales of mica, or covered by it in a thin film, and often are only the continuations of those described under III, of which they are mere varieties.

PARAGENESIS OF SPODUMENE.

The paragenetic relationships between Spodumene and its *original* associates in these granite veins, previous to its alteration, will be more fully discussed in another paper; but the following brief statement will have a bearing on the present purpose.

In the two Goshen veins, they can be only imperfectly studied, from the partially concealed outcrops, though better from the abundant fragments. In the more easterly locality, the veinstone consists mainly of a coarse aggregate of Albite, Indicolite, Garnet, and Spodumene, whose crowded and imperfectly outlined grains indicate a more rapid crystallization than in the other localities. In the Barrus vein, to the west, the mass of the vein seems to be represented in place by a coarse aggregation of white Quartz, Orthoclase, Muscovite, and occasionally greenish Beryl; while the scattered boulders of albitic granite appear to be fragments of a central band or secondary vein, whose slow crystallization is suggested by the beautiful aggregate of snow-white Cleavelandite and grayish-white Quartz, which forms the matrix of the rarer minerals. Of these, the most abundant are the Spodumene, whose habit has been already described, and Tourmaline, black, green, or blue-black (Indicolite), generally massive, but sometimes in good crystals. Less commonly were found Beryl, green, and white (Goshenite), in grains, or sometimes fairly crystallized with good terminations, Garnet, rose-colored Muscovite, and still more rarely Columbite and Cassiterite in minute crystals. Apparently there has been also, in parts of the vein, a final deposition of masses of smoky quartz, enveloping smaller crystals of these minerals, but particularly of green Beryl and Indicolite.

At Macomber's Ledge in Chesterfield, the coarse Orthoclase-granite of the main vein contains films of Margarodite and a few imperfect green Beryls; while in the secondary vein the succession appears to have been, first, Quartz, Muscovite, granu-

lar Albite, Tourmaline, and Spodumene: then Cleavelandite, Quartz, Manganese-Garnet, and Zircon: and finally smoky Quartz, with green and blue Tourmaline. The larger crystals of most of these minerals penetrate through all the layers, and their growth seems to have been continuous.

At Clark's Ledge, in Chesterfield, the main granite-vein is of the same general constitution as that just described, rarely showing a few large Beryls. In the secondary vein no Spodumene occurs, but the succession is in the same order. First, on either wall, a saccharoidal albitic granite, with little Quartz and Mica, and a few scattered imperfect black Tourmalines and Garnets: then coarse Cleavelandite, with blue, green, red, and rarely brown Tourmaline, and small quantities of the rarer minerals, Microlite, Columbite, Cassiterite, Zircon, Cookeite, and Lepidolite; all these, especially the Tourmaline, increase in quantity and development toward the centre of the vein, which is filled up by an irregular sheet of smoky Quartz.

At Chesterfield Hollow, the granite of the main vein is of the usual character, but shows no Beryl and little Mica. The successive deposition of minerals in the secondary vein is first Orthoclase, in huge crystals, large plates of Muscovite, sometimes 6 to 10 inches in diameter, and grayish-white Quartz. Within this comes an irregular mass of a coarse albitic granite, with green Muscovite, Spodumene, greenish-white Beryl, in masses sometimes ten to twenty-five pounds in weight, coarse Garnets, Columbite, in rudely-crystallized grains, up to half a pound in weight, and a Zircon rich in uranium, in minute double pyramids, rarely three-sixteenths of an inch in diameter. Usually this albitic granite passes gradually into a mixture of Quartz and Cleavelandite, in bunches of snow-white plates, enclosing less Muscovite,—Manganese-Garnets in large and abundant but imperfectly crystallized grains,—Zircon,—Spodumene,—and yellowish-white Beryl in irregular masses.

Finally, the core of the vein consists of an irregular sheet of smoky Quartz, penetrated by long prisms of Spodumene,—green Beryl in small and good crystals,—Muscovite, in hexagonal plates, often well crystallized, and up to two or three inches across, as well as in sheets, scattered scales, and wavy films, which in part seem to be altered to Margarodite,—Columbite and Zircon

in rare but perfect crystals. This succession of minerals in the secondary vein is not as regular as might be inferred from the foregoing description, in which it is intended to indicate only the general tendency toward a definite arrangement.

At Walnut Hill, in Huntington, the material of the main vein is similar to that of the preceding locality. In the secondary vein, the first deposit was found to be a very coarse albitic granite, rich in black Tourmaline, in huge masses, Muscovite and Garnet: then followed Cleavelandite, white Quartz, and Spodumene, in the well-known fine crystals, associated with black and blue Tourmaline, Triphylite, Cyrtolite, Garnet, Apatite, Muscovite, and greenish-white Beryl: and the central sheet of smoky Quartz received the terminations of the Spodumene-crystals, together with a little Beryl, Muscovite, and Cyrtolite.

The Spodumene, and in part its associates, in these veins, have been affected by two successive processes of alteration. The one, which may be denominated *Hydro-thermal*, occurred, perhaps before the folding of the strata, during subsidence to that depth below the surface at which they are known to be subjected to the long-continued action of alkaline solutions at a high temperature. The other, to which the term *Meteoric* may be applied, has been continued up to the recent period, with the strata in their present position, by solutions derived from the rain-water, soil, and the decomposed feldspars in the weathered superficies of the main granite-vein.

Hydro-thermal Alteration.

The passage of heated solutions, rich in alkaline silicates, over the crystals of Spodumene, resulted at first in the simple substitution of the alkalies and of water, in various but definite proportions, for the protoxides in that mineral, by the modes of replacement already fully explained. The larger masses were in most cases only superficially altered, but in the smaller and slender crystals the process of substitution became complete.

The alteration first attacked the superficies of a crystal, was hastened by penetration along any existing fissures, and generally progressed most rapidly from the termination of a crystal along the plane of orthodiagonal cleavage. In the brittle, easily fis-

sured, and porous quartz-matrix of the Chesterfield vein, the crystals of Spodumene were thus attacked from all sides; but in the dense compact envelopment of the crystals of the Barrus locality in Goshen, the attack proceeded only in the direction of the longer axis of the prism along the orthodiagonal plane. The formation of the hydrous minerals was then gradually interrupted, and finally ceased, as new conditions of more rapid alteration came into existence, perhaps partly by greater saturation with alkaline and other salts, and partly by increase of temperature. The facts seem strongly to indicate that these conditions varied greatly and frequently, not only in time but in different parts of the vein, and of the same crystal, within even a few inches! Sometimes as the one or the other of the two main alkalies predominated in a percolating solution, alteration-pseudomorphs were produced,—of Albite, by addition of silica and substitution of soda for the more soluble lithium-silicate—and of Muscovite, by substitution of potassa and separation of an equivalent amount of silica in the form of free Quartz. The more rapid character of these processes naturally facilitated the production of displacement-pseudomorphs in Muscovite, Albite, and Quartz, by the complete removal and recombination of constituents.

Meteoric Alteration.

The subsequent process of alteration—or rather decomposition—and one which has continued up to the present time, upon the cores of Spodumene remaining unaltered by the preceding process, has been effected by ordinary meteoric waters, at times holding in solution the acids derived from the decomposition of humus. By ordinary carbonated waters, there has been a gradual removal of a part of the lithia and more soluble protoxides, almost universal, with the consequent effect upon the physical characteristics of the mineral, shown by the loss of weight, lustre, greenish color, and translucency. The channels for the passage of these solutions have been the increased number of fissures in the surrounding gangue, and in the altered crystals themselves, as well as the capillary vacuity along the contact-line between the core of each crystal and its alteration-crust.

In some points the oozing solution became charged from the surface with a content of organic acids and their ammoniacal salts—probably the "azo-humic acids" of Thénard*—combined with potassa derived from the superficial weathering of the granite-bed and decomposition of its Orthoclase. Here a new process of alteration into Killinite ensued, by the de-oxidation of the iron, the removal of the lithia and of a fourth part of the silica, and their partial replacement by potassa, water, and organic matter, with the great change in physical characteristics described under Killinite. The larger cores of Spodumene were affected chiefly at their terminations, and, in a smaller degree, along the sides next the crust of Cymatolite; but smaller crystals have been thus altered completely through. Saturation with this solution has further introduced into Cymatolite its dresent small content of nitrogenous organic matter.

In all these veins there has been a subsequent separation of other substances, through the decomposition of certain minerals by meteoric waters. The Zircons have absorbed water, and lost part of their uranium, which separated as Autunite, Torbernite and, by a further decomposition, Uran-ochre, and perhaps some other constituent, in the form of a pink mineral.

The Garnets, by decomposition, have afforded much ferric oxide in the form of ochre, and manganese in the form of the dendritic films of Pyrolusite which abound in all the veins. The Triphylite of Huntington, by absorption of water and higher oxidation of certain constituents, has assumed its present altered form, so that only small nuclei of the unaltered mineral may sometimes be detected in the heart of a crystal. The Spodumene, especially at Macomber's Ledge, has passed into a crumbling mass, or even an earthy powder, possibly kaolinic, which sometimes becomes a white clay when moist. The Cymatolite also has often become fissured and disintegrated into a clayey mass.

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* Compt. Rend., LXX, 1412.